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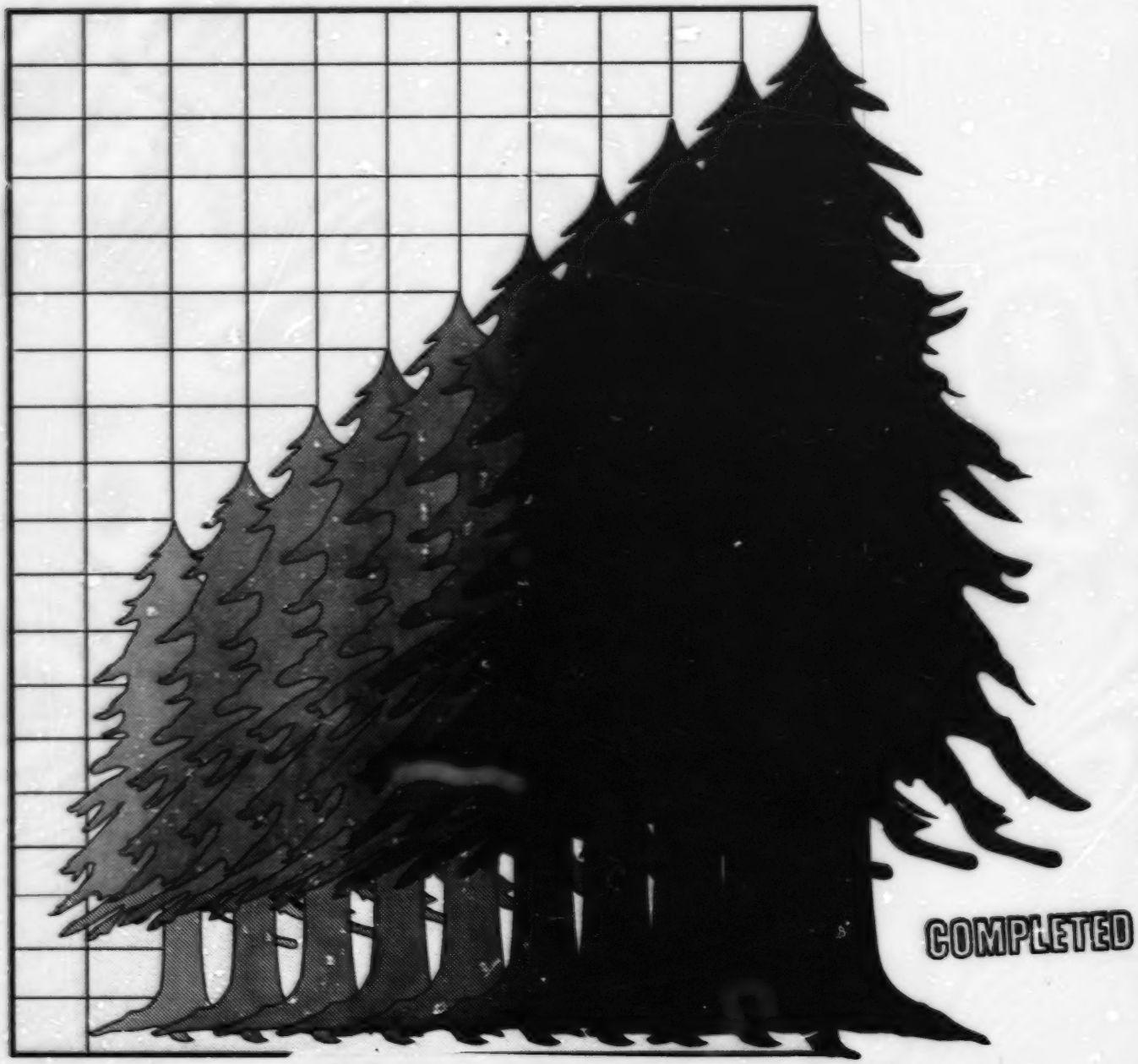
Predicting Height Increment of Young-Growth Mixed Conifers in the Sierra Nevada

K. Leroy Dolph



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IN BRIEF . . .

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Periodic volume increment of individual trees, for a specified growth period, can be estimated if the amount of diameter and height growth during the period can be determined. Diameter growth can be estimated from increment cores but height growth is difficult to determine unless trees are short or destructive sampling methods such as stem analyses are used. Since destructive sampling is costly and time consuming, an indirect procedure for estimating periodic height growth is desirable.

Equations were developed to predict periodic (10-year) height increment for individual trees within the mixed-conifer type of the Sierra Nevada. Two sets of parameter estimates are presented. One set is used when site index information is available for a particular area and tree species. This set of parameters is used to obtain estimates of past or predictions of future periodic height increment. The other set of parameters is applicable when site index data are unavailable.

Tree, stand, and site information were recorded at 150 sample locations, randomly located throughout the mixed-conifer type on the western slopes of the Sierra Nevada. At each location, from 4 to 10 randomly selected trees were felled and sectioned so that 10-year height growth could be accurately measured. Multiple linear regression was then used to relate 10-year height growth of each tree to corresponding tree, stand, and site variables.

Information needed to estimate 10-year height increment of individual trees on a sample plot includes diameter at breast height at the beginning of the growth period, concurrent 10-year diameter growth at breast height (measured from increment cores), and live crown percent of each sample tree, basal area per acre each sample tree represents, and the site variables of latitude, elevation, slope percent, and site index. If site index is unavailable, then total tree height at the start of the growth period is needed to predict height increment.

Depending on tree species, and the presence or absence of site index information, the regressions accounted for 67.1 to 88.5 percent of the variance in observed 10-year height growth. Standard errors of estimate ranged from 1.07 to 2.84 feet.

INTRODUCTION

Estimates of forest growth (increment) are used for evaluating productivity of land and to project growing stock into the future. Since volume is the accepted parameter for measuring forest growth (Spurr 1952), estimates of periodic volume increment for individual trees on inventory plots form the basis for appraising the productivity of the land and timber.

Periodic volume increment of individual trees can be estimated if their dimensions, that is, diameter breast height (d.b.h.) and total height, are measured or calculated at two times. These times are at the beginning and the end of a specified growth period, generally five or ten years in length. Tree volume at the start (V_s) and end (V_e) of the growth period can be obtained from a volume table or volume equation that relates tree volume to d.b.h. and total height. Volume change or increment during the growth period (V_Δ) can then be determined from the difference of these two volume estimates, where

$$V_\Delta = V_e - V_s$$

Periodic increment or periodic annual increment (average annual increment over the growth period) may be based upon any period of time in the past or future, depending upon the intended use. An analysis of recent growth relative to concurrent stand conditions forms the basis for selection of management treatments to increase growth or redistribute it to the most desirable species, age classes, or quality classes (Spada and Pope 1971). Trees on inventory plots are measured for d.b.h. and total height at the end of the most recent growth period. Therefore, an estimate of V_e may be obtained.

However, to obtain an estimate of V_s, values for d.b.h. and total height at the start of the growth period must be determined. Outside bark d.b.h. at the start of the growth period can be found by subtracting total diameter growth for the period from the current d.b.h. Total diameter growth includes the growth of both wood and bark. Wood growth may be easily measured from increment cores. An estimate of the periodic change in bark thickness may be obtained by multiplying the diameter wood growth by a species dependent bark adjustment factor (Dolph 1984). Determining total height at the start of the growth period presents the largest problem in obtaining an estimate of V_s. Where trees are short and annual branch whorls are distinct, the periodic change in total height can be measured using extendible graduated poles and counting branch whorls corresponding to each year of the growth period. However, if trees are tall, or branch whorls are not distinct, measurement error is likely to exceed the height growth, and an indirect procedure is preferable.

This paper describes the development of linear regression equations for estimating periodic (10-year) height increment of individual trees for six mixed-conifer species on the western slope of the Sierra Nevada in California. The equations predict periodic height increment as a function of initial tree size and competitive status, concurrent diameter increment, and site conditions. The predictive equations can be used to estimate the height increment component of current volume increment with the statistical reliability described.

These same equations can be imbedded in a stand growth simulator to predict the height increment component of periodic volume increment. However, when the equations are applied in such a system, estimates of diameter increment instead of measured values must be used. The resulting height increment predictions therefore will be less reliable than the statistics presented here indicate, depending on the accuracy of the diameter increment predictions.

STUDY AREA

The study area occupies mid-elevations on the west slope of the Sierra Nevada, extending approximately 350 miles north to south from 40°00' to 35°25'N. latitude. Data were collected within the boundaries of the six National Forests extending from the northern boundary of the Plumas National Forest to the southern boundary of the Sequoia National Forest. The other four National Forests included are the Tahoe, Eldorado, Stanislaus, and Sierra. Within this area, elevational limits of the mixed-conifer type vary with changes in latitude and aspect. Most of the type is found between 3000 and 7000 ft (900 and 2130 m) elevation, below the red fir (*Abies magnifica* A. Murr.) and lodgepole pine (*Pinus contorta* Dougl. ex Loud.) types, and above the drier foothill types.

The mixed-conifer type typically occurs on productive sites of the westside Sierra Nevada, where precipitation and seasonal temperatures occur in the most favorable combination (abundant winter precipitation followed by long, warm growing seasons). Conifer species in this type are California white fir (*Abies concolor* var. *lowiana* [Gord.] Lemm.) incense-cedar (*Libocedrus decurrens* Torr.), Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), ponderosa pine (*Pinus ponderosa* Dougl. ex Laws. var. *ponderosa*), and sugar pine (*Pinus lambertiana* Dougl.). Stands occur as variable mixtures of species or as small groups of single species. Jeffrey pine (*Pinus jeffreyi* Grev. & Balf.) is often an associate at upper elevations and also occurs on serpentine soils. Hardwood associates are California black oak (*Quercus kelloggii* Newb.), Pacific madrone (*Arbutus menziesii* Pursh), tanoak (*Lithocarpus densiflorus* [Hook. & Arn.] Rehd.), and Pacific dogwood (*Cornus nuttallii* Audubon) (Helms 1980).

METHODS

Young-growth natural stands which fit the definition of Sierra Nevada Mixed Conifer Type (Tappeiner 1980) were randomly sampled throughout the western slopes of the Sierra Nevada. Each sample location consisted of a cluster of five plots arranged in an L shape, with plot centers located 132 feet apart along north and east compass lines. Each plot was evaluated for study suitability by the following criteria:

- Young-growth—No more than 25 percent of the trees tallied were older than 80 years at breast height.
- Mixed-conifer type—No more than 20 percent of the trees tallied were conifer species other than those characteristic of the mixed-conifer type. Evidence of white fir regeneration in the stand or surrounding area was required, also.
- Homogeneous site—No more than one distinct soil type, slope percentage, or aspect was present on a 1/5 acre circular plot around the plot center (radius 52.7 ft).
- Untreated stand—No evidence of silvicultural treatment during the 10 years prior to measurement.

A cluster was retained as a suitable sample point if two or more plots met the above criteria.

Stand and Tree Measurements

Basal area per acre was determined at each plot center by counting all trees that qualified for tallying with a wedge prism. Prisms with basal area factors of 20, 40, or 60 were used depending on stand composition. Each tally tree was assigned a tree number and the following characteristics and measurements were recorded for each.

- Species
- D.b.h.(outside bark)
- Crown position
- Damage, defect, and tree class
- Total height
- Height to base of live crown

On each conifer tree 3.0 inches (7.6 cm) d.b.h. and larger, age and past 10-year radial growth were measured from increment cores extracted at breast height (4.5 ft [1.4 m] above the ground on the uphill side of the tree). Radial growth for the past 10-year period was measured to the nearest 0.05 inch (0.13 cm), using a hand lens when necessary.

Two trees, on the average, at each plot were then felled and sectioned to determine 10-year height growth. A random number table was used to determine which trees would be sampled for height growth. Trees older than 80 years at breast height and trees with dead, broken, or otherwise deformed tops were not sampled. Since stem analysis trees were selected randomly, the resulting sample covered the range of diameters, heights, and crown classes typical of young-growth stands *(table 1)*.

Each tree was marked at breast height before felling and all subsequent height measurements were taken from this reference point after the tree was on the ground. Height to the tip of the tree, excluding the current season's growth, was recorded first. Height of the tree when growth started 10 years ago was determined next by cutting cross-sections down the stem until the lowest section that contained 10 complete growth rings was found. Height to this section was then recorded. Height increment for the growth period was determined from the difference of these two measurements.

The d.b.h. of each tree, at the start of the most recent 10-year growth period, was determined using the radial wood growth measurement and a backdating procedure. The backdating procedure for young-growth mixed conifers is described in another report (Dolph 1988). The past d.b.h. values were then combined for each plot and past basal area per acre and basal area in larger trees were obtained. Of necessity, live crown percent measured at the end of the growth period, was assumed constant over the period. During a 10-year period, live crown percent changes slowly (Stage 1975).

Site Factors

Slope percent and aspect were measured on each individual plot. Site factors recorded for the entire plot cluster included:

- Elevation of the vertex plot of the L-shaped cluster, determined from U.S. Geological Survey maps and recorded to the nearest 100 feet
- Latitude of the cluster, recorded to the nearest minute
- Soil characteristics, recorded near the center of that plot which appeared most typical of the cluster. Soil pits were dug to a depth of 48 inches, or to bedrock, whichever occurred first. Soil horizons were described and representative samples of each were collected for laboratory analyses. In the laboratory, the particle size distribution of each horizon was determined by the hydrometer method following standard procedures (Day 1965). Soil chemical properties were not tested because mixed conifer ecosystems are generally more limited by moisture stress (which is related to physical soil properties) than by nutrient status.

Table 1—*Distribution of sample trees at the start of the 10-year growth period by diameter, height, and species*

Species	Trees	D.b.h. range	Average D.b.h.	Ht range	Average ht
		inches	*inches*	*feet*	*feet*
White fir	407	2.6 - 27.8	11.7	11.3 -112.8	52.0
Incense-cedar	208	2.2 - 30.8	8.9	9.1 - 94.1	33.4
Ponderosa pine	158	2.6 - 27.6	12.7	9.8 -111.5	59.2
Sugar pine	68	1.9 - 24.3	11.7	8.5 - 99.1	49.7
Jeffrey pine	31	4.3 - 24.3	13.9	15.5 - 88.3	52.8
Douglas-fir	46	2.3 - 26.0	10.6	11.3 -113.4	55.1

DATA ANALYSIS

Three groups of variables were suspected to affect height growth of the individual trees: (1) tree size and vigor, (2) competitive status, and (3) site factor variables. Combinations of the following independent variables and transformations of several of these variables were initially tested for predicting 10-year height increment using all possible subsets regression (computer program BMDP P9R) (Frane 1981):

Tree size and vigor
- D.b.h.
- Total height
- Percent live crown
- Concurrent 10-year diameter growth

Competitive status
- Plot basal area/acre
- Basal area in larger trees
- (Basal area in larger trees)/(d.b.h. of the subject tree)

Site factor variables
- Latitude
- Elevation
- Slope
- Aspect
- Total soil depth
- Percent coarse fragments within the soil profile
- Soil particle size class
- Site index

Criteria for selecting the subsets that best explained the variation in height growth were these: the multiple correlation coefficient (R^2) and Mallows' measure of total squared error (Cp), those with fewest terms, ease of measuring the variables in the field, and, those which contained variables all having low variance inflation factors (VIF's). The choice of best subsets was therefore partially subjective.

Two forms of the dependent variable, 10-year height increment and the natural logarithm of 10-year height increment, were tested. Regardless of the combination of independent variables, selection criteria (R^2 and Cp) were nearly the same magnitude using either dependent variable. Since the logarithmic transformation results in bias being introduced when predictions are transformed back into natural units (Flewelling and Pienaar 1981), untransformed height increment was chosen for the dependent variable.

After the best subsets of predictor variables were identified, the regression coefficients, standard errors, R^2's, and VIF's were computed using Minitab (Ryan and others 1985).

RESULTS

The basic model for the multiple linear regressions predicts periodic height increments of individual trees, dependent on tree, stand, and site characteristics.

Predictive Model

The model is expressed as:

$$HG = LAT + b_1X_1 + b_2X_2 + \ldots\ldots b_{16}X_{16} + (b_{17}X_{17})$$

in which

HG = periodic 10-year height growth in feet

LAT = intercept term dependent on species and latitude

X_1 = (DBH)...diameter of the subject tree in inches, outside bark, at the beginning of the growth period

X_2 = (lnDBH)...natural logarithm of DBH

X_3 = (DSQ)...DBH squared

X_4 = (lnHT)...natural logarithm of total tree height in feet at the beginning of the growth period

X_5 = (LCP)...live crown percent, expressed as the ratio of live crown length to total tree height

X_6 = (DG)...average 10-year diameter wood growth at breast height, in inches

X_7 = (SRDG)...square root of DG

X_8 = (BAI)...tree basal area increment $[(DBH + DG)^2 - DSQ]$

X_9 = (BA)...total basal area of trees on the sample plot, in square feet per acre, at the beginning of the growth period

X_{10} = (lnBA)...natural logarithm of plot BA

X_{11} = (BLT)...total basal area (square feet per acre) of all trees on the sample plot that are larger than the subject tree at the start of the growth period

X_{12} = (BLTD)...BLT divided by DBH of the subject tree

X_{13} = (EL)...elevation in hundreds of feet

X_{14} = (ELSQ)...EL squared

X_{15} = (SL)...slope of the sample plot in percent

X_{16} = (SLSQ)...SL squared

X_{17} = (SI)...site index for the species of the subject tree, expressed as total height in feet of dominant or codominant trees at a reference age of 50 years at breast height (if site index data are unavailable, the value of this variable is set to zero and parameter estimates given *(table 2)* are applicable).

$b_1, b_2 \ldots b_{17}$ = parameter estimates

Although this basic model was used for each regression, all of the parameter estimates were not significant for all species. Only those parameters significant at least at the 0.05 level are included.

Estimates of site index are not always available or often cannot be obtained due to the lack of suitable "site" trees on a given plot. Therefore, two sets of parameter estimates are presented for each species, one with and the other without site index as an independent variable. If site index information is not available, the parameters in the first set *(table 2)* are applicable. With site index data, the second set of parameters *(table 3)* will produce better predictions of 10-year height increment.

Statistics quantifying the fit of the equations are shown for each species both with and without site index *(table 4)*.

Each tree was treated as an independent observation for the development of the predictive equations. In actuality, the clusters (which were selected randomly) are the experimental units and tree measurements are subsamples within the clusters. If more than one tree had been measured at each cluster, ignoring this random cluster effect would result in an underestimate of the variance associated with each regression. However, since only

Table 2—*Coefficients for the height increment model, by species, when site index data are not available*

Variables	Coefficients by species					
	White fir	Incense-cedar	Ponderosa pine	Sugar pine	Jeffrey pine	Douglas-fir
Latitude (degrees)						
35-35.9	-14.171	-2.586	-7.829	-24.258	-0.845	(1)
36-36.9	-12.365	-2.586	-7.829	-18.070	-0.845	(1)
37-37.9	-12.365	-2.586	-7.829	-18.070	-0.845	-35.606
38-38.9	-12.365	-2.586	-6.383	-18.070	2.547	-35.606
≥ 39	-12.365	-3.508	-7.829	-18.070	-0.845	-37.851
DBH (b_2)	-0.2907					
lnDBH (b_3)		-1.4360				
DSQ (b_5)			-0.0067	-0.0130		
lnHT (b_6)	2.1108	2.3732	1.5304	1.5230		
LCP (b_9)	0.0300					
DG (b_4)			4.2988		3.9903	
SRDG (b_7)	10.8291	7.6794		12.5910		15.3330
SAI (b_8)						-0.0454
BA (b_9)		0.0074				-0.0303
lnBA (b_{10})	1.0246		1.4066	1.5955		7.0900
BLT (b_{11})	0.0058	-0.0073			0.0205	
BLTD (b_{12})			-0.0753			
EL (b_{13})	-0.0683	-0.1067				
SLSQ (b_{14})	6.6630					

[1] No Douglas-fir were sampled within this range of latitude.

Table 3—*Coefficients for the height increment model, by species, when site index data are available*

Variables	Coefficients by species					
	White fir	Incense-cedar	Ponderosa pine	Sugar pine	Jeffrey pine	Douglas-fir
Latitude (degrees)						
35-35.9	-12.246	-3.831	-5.554	-14.053	-0.268	(1)
36-36.9	-10.685	1.711	-5.554	-14.053	-0.268	(1)
37-37.9	-10.685	-3.831	-5.554	-14.053	-0.268	-39.027
38-38.9	-10.685	-2.898	-4.282	-14.053	3.097	-39.027
≥ 39	-10.685	-3.831	-5.554	-14.053	-0.268	-39.027
DSQ (b_5)	-0.0098		-0.0086	-0.0098	-0.0082	
LCP (b_9)	0.0363					
DG (b_4)			3.7974		2.9620	
SRDG (b_7)	8.7587	6.5757		10.1890		15.3820
BAI (b_8)						-0.0694
BA (b_9)		0.0080				-0.0285
lnBA (b_{10})	1.2324		1.4843	1.2845		6.1190
BLT (b_{11})		-0.0079	-0.0142			
BLTD (b_{12})	-0.0399					
EL (b_{13})	-0.0453					
ELSQ (b_{14})		-0.0007				
SL (b_{15})	3.2180					
SI (b_{17})	0.0713	0.0643	0.0598	0.0881	0.0687	0.0974

[1] No Douglas-fir were sampled within this range of latitude.

Table 4—*Statistics for periodic height increment equations*

Species	Equation type[1]	Observations	Standard error of estimate	R^2
White fir	1	407	2.687	0.671
	2	406	2.471	.721
Incense-cedar	1	208	1.703	.747
	2	198	1.572	.783
Ponderosa pine	1	158	2.476	.692
	2	155	2.353	.718
Sugar pine	1	68	2.493	.745
	2	64	2.239	.793
Jeffrey pine	1	31	1.195	.850
	2	30	1.071	.885
Douglas-fir	1	46	2.843	.752
	2	46	2.635	.787

[1] 1 = without site index; 2 = with site index in the model.

a few trees were sampled for height growth at each cluster and these were often distributed among two or more species, on many clusters only one tree of a given species was sampled. For example, sugar pine trees were sampled on 49 clusters but 36 clusters were represented by only one tree. Therefore, the random cluster effect was not considered significant in calculating the variance estimates associated with the regressions.

Confidence Limits

Putting confidence limits on multiple regressions requires computation of the Gauss or c-multipliers. The c-multipliers are the elements of the inverse matrix for sums of squares and products as they appear in the normal equations. The inverse matrices for each species and for each type of equation (with and without site index) are not presented in this paper. They are available to anyone wishing to define confidence intervals for any combination of species and independent variables.[1] General formulas for confidence limits and a specific example are presented here only to illustrate the calculation method and show a typical range of values.

Confidence limits on the expected mean value of HG (a predicted value of mean HG for a specified set of independent variables) not only change by species but also vary with different values of the independent variables. The confidence interval is given by Freese (1964).

$$\widehat{HG} \pm t \cdot [\text{estimated variance of } \widehat{HG}]^{1/2}$$

in which

t = "Student's"- t value for the desired probability level with $(n_o - n_p)$ degrees of freedom where n_o equals the number of observations and n_p equals the number of estimated parameters.

[1] Data on file at Pacific Southwest Forest and Range Experiment Station, 2400 Washington Avenue, Redding, California 96001.

The variance of HG is equal to

$$\left(\sum_{i=0}^{p}\sum_{j=0}^{p} c_{ij}x_i x_j\right)(\text{residual mean square})$$

in which c_{ij} are the c-multipliers, x_i and x_j are values of the independent variables (where x_i or $x_j = 1$, if i or j = 0), and p equals the total number of independent variables.

To demonstrate the model and calculation of the confidence limits, a 12.0-inch d.b.h. sugar pine will be used. The plot basal area at the beginning of the growth period was 140 sq.ft. per acre, site index equals 70.0 feet, and past 10-year diameter growth (from increment core measurements) is 2.5 inches. Therefore, the variables needed for the model are:

DSQ = 144.0
SRDG = 1.5811
lnBA = 4.94164
SI = 70.0

Using the appropriate model coefficients *(table 3)*, the estimated 10-year height growth is calculated to be 13.2 feet. For this specific combination of independent variables, the 95 percent confidence interval for the predicted value of mean HG is

in which $13.2 \pm 2.00 \cdot \sqrt{(0.0237)(5.0131)}$

2.00 = t value for the 95 percent probability level

$$0.0237 = \sum_{i=0}^{p}\sum_{j=0}^{p} c_{ij}x_i x_j$$

5.0131 = residual mean square

The confidence interval therefore equals 12.46 to 13.84 feet. Thus, we can say that there is a 0.95 probability that the true mean will be covered by intervals constructed in such a manner.

The limits previously discussed are limits for the regression surface at a specified point, not limits on individual values of $\widehat{HG}$. Having estimated a value of $\widehat{HG}$ by means of the regression equation, we would like to have some idea as to the limits which might include most of the individual $\widehat{HG}$ values associated with a specific set of independent variables. These limits can be obtained by adding the residual mean square to the estimated variance of $\widehat{HG}$ in the equations given for the limits on the regression (Freese 1964). This would make the limits on an individual value of $\widehat{HG}$

$$\widehat{HG} \pm t \cdot \sqrt{\left(1 + \sum_{i=0}^{p}\sum_{j=0}^{p} c_{ij}x_i x_j\right)(\text{residual mean square})}$$

The 95 percent prediction interval for an individual value of HG for the combination of independent variables in the example is:

$$13.2 \pm 2.00 \cdot \sqrt{(1 + 0.0237)(5.0131)}$$

which equals 8.62 to 17.68 feet.

Thus, over the long run, an observed value of $\widehat{HG}$ will be within intervals constructed in this manner 19 times out of 20 for this specific combination of independent variables.

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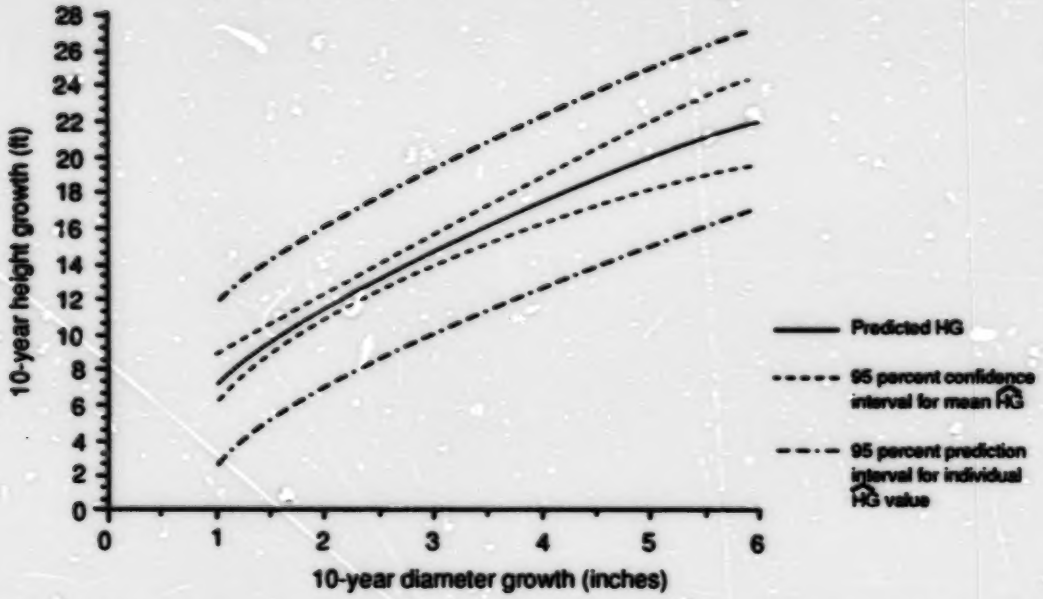

Figure 1- Example of 95 percent confidence and prediction intervals for 10-year height growth of a 12-inch d.b.h. sugar pine as 10-year diameter growth varies from 1 to 6 inches with other independent variables held constant (BA = 140 sq ft / acre, SI = 70 ft).

Hypothetical confidence and prediction intervals were computed for $\widehat{HG}$ of a 12-inch d.b.h. sugar pine as diameter growth varies from 1 to 6 inches with the other independent variables held constant *(fig. 1)*.

DISCUSSION

As expected, periodic diameter increment is the independent variable most strongly correlated with periodic height increment. Diameter increment indicates the combined effects of all environmental factors and the tree's individual characteristics, is much more easily measured than height increment, and responds to the same growth determinants (Stage 1975). Diameter growth (DG) or its square root transformation (SRDG) was significant at the 0.001 level or higher for each of the mixed-conifer species. Besides the effects of latitude and site index, the only other site factor variables significantly correlated to HG were slope and elevation and only for the species white fir and incense-cedar.

Transformations of slope and aspect as described by Stage (1976) were not significant either with or without site index in the model. Variables which described soil characteristics at each location: total soil depth, coarse fragment content, and particle-size class of the control section (weighted by horizon depth), were included in the initial screening of the independent variables. No strong correlations were found between any of these soil factors and 10-year height increment.

Equations for predicting height increment of conifer species in northern Idaho and western Montana (Stage 1975; Wykoff and others 1982) were developed using the logarithm of 10-year periodic height growth as the dependent variable. The logarithmic transformation was used to decrease the variance of the residuals associated with large predictions. In contrast to their results, plots of the residuals for the six mixed-conifer species of the Sierra Nevada, using untransformed height growth as the dependent variable, indicate that the residuals follow a normal distribution, and when plotted against the predicted value of HG, the overall impression of the horizontal bands indicates no abnormalities; the assumption of a constant variance does not appear to be violated. Examples of these plots are shown for white fir *(fig. 2)* and ponderosa pine *(fig. 3)*. One reason the log transformation was not required may be the young-growth aspect of this study. No trees over 80 years old at breast height were included in the analysis. If older and larger trees had been included, the log transformation may have been appropriate to model the decline in growth rate of the older trees. Therefore, height increments calculated for trees with breast-height ages greater than 80 years should be used with caution because such estimates are made with extrapolations of the basic data.

```
Midpoint  Count
   -9.00      1  *
   -8.00      1  *
   -7.00      1  *
   -6.00      6  ***
   -5.00      7  ****
   -4.00     18  **********
   -3.00     34  ********************
   -2.00     43  *************************
   -1.00     59  **********************************
    0.00     66  ***************************************
    1.00     56  *********************************
    2.00     48  ****************************
    3.00     34  ********************
    4.00     12  *******
    5.00      8  ****
    6.00      5  ***
    7.00      2  *
    8.00      3  **
    9.00      1  *
```

Figure 2–Histogram of frequency of residuals for white fir. Midpoints are given for each residual class with increments of 1.00 feet. Each * represents two or less observations and total observations equals 407 trees.

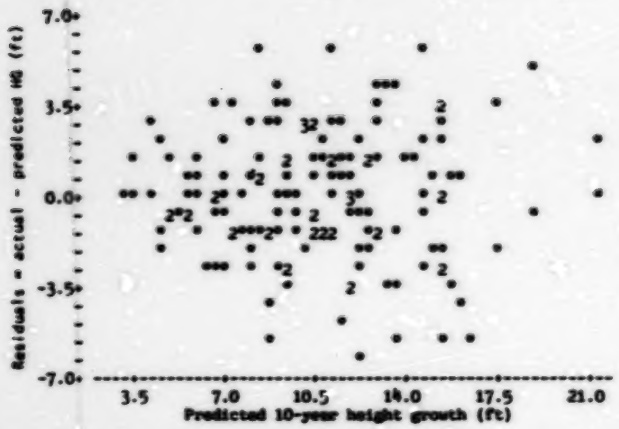

Figure 3–Plot of residual against the predicted value of 10 year height growth for ponderosa pine. Each * represents one observation. More than one observation at a given point is represented by the actual number. Total number of observations equals 158.

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Periodic (10-year) height increment of individual trees for young-growth mixed-conifer species in the Sierra Nevada can be predicted from initial tree size and competitive status, concurrent diameter increment, and site conditions. The predictive model was calibrated for six species: California white fir, incense-cedar, ponderosa pine, sugar pine, Jeffrey pine, and Douglas-fir.

Retrieval Terms: stem analysis, increment (height), California white fir, incense-cedar, ponderosa pine, sugar pine, Jeffrey pine, Douglas-fir, Sierra Nevada, California